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AD NUMBER
AD005578
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SECURITY INFORMATION

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ROYAL AIRCRAFT ESTABLISHMENT

F A R N B O R O U G H, H A N T S

TECHNICAL NOTE No: ARM.508

BOMB CASE DEFLECTIONS UNDER STACKING LOADS

by

J.T.GANDY, B.Sc.(Eng.), A.M.I.Mech.E.

RESTRICTED

SECURITY INFORMATION

U.D.C. No. 623.451.746.1.087 : 539.383

Technical Note No. Arm.508

December, 1952

ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH

Bomb Case Deflections Under Stacking Loads

by

J. T. Gandy, B.Sc. (Eng), A.M.I.Mech.E

SUMMARY

To determine the maximum safe stacking height for any particular bomb it is necessary to know the rate of deflection of the bomb case under the transverse compressive loads obtained in stacking.

In this note, compression tests on bomb cases are analysed and the maximum deflections (change in diameter of case) to be expected under stacking conditions are stated for the following stores:-

Bombs H.E., A/C, G.P., 250 lb, 500 lb and 1000 lb.

Bombs H.E., A/C, M.C., 250 lb, 500 lb and 1000 lb.

Bombs H.E., A/C, A.P., 2000 lb.

The maximum deflections given enable a safe stacking height to be deduced for each store from a knowledge of the maximum allowable disturbance of filling.

LIST OF CONTENTS

LIST OF APPENDICES

LIST OF ILLUSTRATIONS

1 Introduction

1.1 Information on bomb case deflections during stacking was required for the following stores.

Bombs H.E., A/C, G.P., 250 lb, 500 lb and 1000 lb.
Bombs H.E., A/C, M.C., 250 lb, 500 lb and 1000 lb.
Bombs H.E., A/C, A.P., 2000 lb.

1.2 The load deflection rate for the bomb case under the transverse compressive loads due to stacking is a principal factor in determining the maximum height of stacking for a particular bomb. This note describes compression tests carried out to determine the most severe deflections of case obtained with the above stores under the loads due to stacking. Using these results in conjunction with a knowledge of the maximum allowable disturbance of the filling, it is possible to deduce a safe stacking height for each store. No attempt is made to state safe stacking heights in the present note.

1.3 Relevant details, from the manufacturing drawings, of the various marks of the stores (para.1.1) which have been considered are given in Appendix I.

2 Stores selected for test

2.1 The above stores (para.1.1) can be arranged in two groups:

(a) Those up to 12.9 ins. external diameter.

(b) Those between 12.9 ins. and 17.5 ins. external diameter.

From considerations of thickness and length of case the store in group (a) having the least resistance to transverse compressive loads is the 500 lb M.C. bomb, and the corresponding store from group (b) is the 1000 lb M.C. bomb. Tests were therefore applied to an empty 500 lb M.C. bomb case and to an empty 1000 lb M.C. bomb case to determine the greatest deflections obtainable when stacking bombs from either group.

2.2 Relevant details of the two specimens tested as given on the manufacturing drawings are as follows:

500 lb M.C. bomb case:

External diameter: 12.9 ins. at maximum section
Thickness of case: 0.285 ins. minimum
Overall length of case: 42.0 ins.

1000 lb M.C. bomb case:

External diameter: 17.5 ins. at maximum section
Thickness of case: 0.480 ins. minimum
Overall length of case: 50.15 ins.

2.3 Each specimen case was tested with the fuze pocket and plug in position at the forward end and with the end plug in position at the rear end. As already stated, the tests were applied to empty bomb cases.

3 Tests applied

3.1 The tests were based upon the conditions of storage where bombs are stacked in layers with intervening battens of wood as shown in Fig.1. The battens are assumed to have negligible stiffness so that in elevation the stack must consist of rows and columns with the weight of each column of stores transferred vertically to the two battens which support the whole stack.

3.2 The two specimens were tested by applying equal and opposite loads in a testing machine as shown in Fig.2. The loads were applied through 2 ins. square mild steel blocks having flat faces in contact with the case. Each specimen was subjected to two tests. In the first test loads were applied near one end of the case and in the second test loads were applied in a plane near the suspension lug about half way along the parallel part of the body. The exact positions of loading are given in the Appendices II and III with the test results.

3.3 The initial increments of load were based upon the approximate maximum load on one of two battens arranged in typical positions and supporting a single bomb. In the tests on the 500 lb M.C. bomb case the maximum load on a batten due to one bomb was taken to be 261.5 lb and the corresponding load with the 1000 lb M.C. bomb was taken as 612 lb. Thus, on this basis, the maximum contact load on one of two battens supporting 10 tiers of 500 lb M.C. bombs was assumed to be 261.5 × 10 = 2165 lb.

3.4 Deflections were measured as changes in the diameter of the case by dial indicators arranged at opposite corners of the travelling head of the testing machine as shown in Fig.2.

4 Results of tests

4.1 The loads applied in the tests and the corresponding deflections are recorded in Appendices II and III. Deflections are everywhere given as changes in diameter in the direction of the applied loads.

4.2 When the two tests (para.3.2) on each specimen were completed a small portion of the case surrounding each loading point was cut out and the thicknesses t_1 and t_2 measured. In the plane near the suspension lug, in which the loads were applied in the second test, portions of each case were also cut out and the thicknesses t_3 and t_4 measured at positions equidistant from the loading points (see Fig.1 Appendix II and Fig.1 Appendix III). The results of these measurements are recorded in the Appendices II and III with the test results.

5 Deflections with minimum thicknesses of case

5.1 The thickness of case of the specimens tested measured in the planes of loading (para.4.2) was everywhere greater than the corresponding minimum thickness specified on the manufacturing drawings (para.2.2). It is necessary to obtain a correction factor for each set of results by which the observed deflection, y, can be multiplied to give the corresponding deflection, y_o, which would have been obtained with a case of minimum thickness. If the correction factor factor is denoted by k_1, say, then

$$y_o = k_1 y \tag{1}$$

5.2 An approximate value for k_1 (para.5.1) can be derived on the assumption that the ratio of the deflections y and y_o produced by equal and opposite loads W applied in the same manner to two different bomb cases, one of a non-uniform thickness and the other of uniform thickness t_o but otherwise similar, is the same as the corresponding ratio for loads applied

in the same way to circular rings of uniform width and of corresponding thicknesses and diameter. This assumption appears satisfactory for those tests in which the loads were applied, as shown in Fig.1 Appendix II and Fig.1 Appendix III, in a plane near the suspension lug away from the constraint of the ends of the case.

5.3 A further assumption is required with regard to the variation of the thickness of the case in the plane of loading between the points at which the thickness was measured. Here it is assumed that the thickness measured at any one of two or four points in a plane of loading extended circumferentially, in the same plane, to positions halfway to the adjacent points on either side as indicated in Fig.1 Appendix II and Fig.1 Appendix III where $\alpha_1 \ldots \alpha_4$ denote arcs over which the thicknesses $t_1 \ldots t_4$, respectively were assumed to extend.

5.4 On the foregoing assumptions (paras.5.2 and 5.3), if the thicknesses t_1 and t_2 are known only at the loading points the correction factor to be applied is

$$k_1 = \frac{2}{t_o^3(t_1^{-3} + t_2^{-3})} \qquad (2)$$

where t_o is the least thickness of case allowed by the manufacturing tolerances. If, in addition, the thicknesses t_3 and t_4 are known at two positions in the plane of loading equidistant from the loading points at which t_1 and t_2 are measured then the (more accurate) correction factor is

$$k_2 = \frac{4.97}{t_o^3[1.47(t_1^{-3} + t_2^{-3}) + t_3^{-3} + t_4^{-3}]} \qquad (3)$$

The derivation of k_1 and k_2 analogy with a circular ring of uniform width is given in Appendix IV.

5.5 The deflections obtained in each test have been corrected to minimum thickness of case by the appropriate factor k_1 or k_2 as indicated and the corrected deflections are recorded with the observed deflections in the Appendices II and III. The results of test 2 on each specimen are also shown plotted in Fig.1, Appendix II and Fig.1, Appendix III.

5.6 The corrections to minimum thickness of case are only required in applying the test results to the M.C. bombs. The test results have been applied directly to the other stores which all have a specified minimum thickness of case greater than the thickness of the corresponding test specimen.

6 Discussion

6.1 In the first and second of the two tests carried out on each specimen the loads were applied in planes (1) near the end of the body and (2) in the region of the suspension lug, near the mid-length position respectively. The purpose of the first test was to check that there would be no unusually large deflections due to end effects but, as was expected, the deflections near the ends were less severe than those obtained near the suspension lug. Although the conditions of loading, particularly in the second test on each specimen, were more severe than in practice (paras.3.1 and 6.2) the deflections obtained in the second tests appeared sufficiently small to form a

basis for the determination of any practicable stacking height. The results of the second tests were also considered to be of more general application because the loads were applied in planes away from the end effects peculiar to the specimens chosen for test. Attention was therefore concentrated on the results of the second of the two tests on each specimen and a more accurate correction factor for minimum thickness of case (para.5.4) was obtained by measuring the case thickness in the plane of loading at four points instead of two.

6.2 In applying the results of the second tests (test 2 Appendix II and test 2 Appendix III) to practical conditions of stacking it should be noted that the test conditions were more severe than in practice in the following particulars:

(a) The loads were applied in the tests through 2 ins. square steel blocks with flat faces in contact with the bomb case whereas in practice wood battens are used, generally of larger section than 2 ins. square.

(b) In the second test on each specimen (test 2 Appendix II and test 2 Appendix III) the loads were applied in the region of the suspension lug near the middle of the case whereas in practice battens are placed nearer the ends where the case is stronger.

(c) Equal and opposite loads were applied in the tests whereas in practice the total upper and lower contact loads on opposite sides of the bomb case differ by the weight of one bomb.

(d) Empty bomb cases were tested whereas in practice the case is partially supported against compressive loads by the filling.

6.3 Over the range covered by the tests the deflection of the case of the lowest bomb appears to be a linear function of the number of tiers in the stack and the permanent set after the application of the maximum load is small in all the tests applied.

6.4 From the test results plotted in Fig.1 Appendix II and Fig.1 Appendix III it is concluded that the deflection (change in diameter) of the lowest bombs in a stack will not exceed the values given in Table I (p.7) which are obtained from the test results in accordance with paras. 5.5 and 5.6 as follows:

The deflections given for the 250 lb, 500 lb and 1000 lb G.P. bombs are taken, respectively, as half the actual deflections and the actual deflections from Fig.1 Appendix II and the actual deflections from Fig.1 Appendix III. The deflections given for the 250 lb, 500 lb and 1000 lb M.C. bombs and the 2000 lb A.P. bomb are taken, respectively, as half the corrected deflections and the corrected deflections from Fig.1 Appendix II and the corrected deflections and twice the actual deflections from Fig.1 Appendix III

/Table

Table I Maximum deflection of bomb cases in stacking (Based upon the test results applied to the stores listed in Appendix I)							
Number of tiers in stack	Maximum deflection (change in diameter) of lowest bomb case in stack						
	250 lb G.P. bomb ins.	500 lb G.P. bomb ins.	1000 lb G.P. bomb ins.	2000 lb A.P. bomb ins.	250 lb M.C. bomb ins.	500 lb M.C. bomb ins.	1000 lb M.C. bomb ins.
8			0.006	0.012			0.01
10	0.002	0.0036	0.012	0.024	0.005	0.010	0.02
12	0.0036	0.0073	0.018	0.036	0.010	0.020	0.031
14	0.0055	0.011	0.024	0.048	0.015	0.030	0.041
16	0.0073	0.0145	0.030	0.060	0.020	0.040	0.052
18	0.0091	0.0181	0.036	0.072	0.025	0.050	0.062
20	0.0109	0.0218	0.042	0.084	0.030	0.060	0.072
22	0.0127	0.0254	0.048	0.096	0.035	0.070	0.082
24	0.0145	0.029	0.054	0.108	0.040	0.080	0.093
26	0.0163	0.0327	0.060		0.045	0.090	0.103
28	0.0181	0.0363	0.066		0.050	0.100	0.113
30	0.020	0.040	0.072		0.055	0.110	0.123
40	0.029	0.058	0.102		0.080	0.160	0.174
50	0.038	0.076	0.132		0.105	0.210	0.225
60			0.161				0.276

6.5 The practical height of any bomb stack is limited by one or more of the following considerations:

(1) Height of revetments in open storage.

(2) Height of capacity of lifting tackle.

(3) Strength of floor or foundation.

(4) Height available (e.g. in hold of ship).

It is unlikely that the maximum height will ever exceed 20 ft which, with allowances for the thicknesses of the intervening battens corresponds roughly to the maximum number of tiers indicated in Table II.

Table II Approximate maximum number of tiers in a bomb stack 20 feet high	
Type of Bomb	Approximate maximum number of tiers in 20 ft
250 lb G.P.	20
250 lb M.C.	20
500 lb G.P.	16
500 lb M.C.	16
1000 lb G.P.	12
1000 lb M.C.	12
2000 lb A.P.	14

7 Conclusions

7.1 Assuming 20 ft as the maximum height of stack it is seen from Tables I and II that the respective maximum deflections (change in diameter) of the bomb cases will not exceed:

0.011 ins. and 0.030 ins. for the 250 lb G.P. and 250 lb M.C. bombs.

0.015 ins. and 0.040 ins. for the 500 lb G.P. and 500 lb M.C. bombs.

0.018 ins. and 0.0310 ins. for the 1000 lb G.P. and 1000 lb M.C. bombs.

0.048 ins. for the 2000 lb A.P. bomb.

These deflections are probably greater than the actual deflections produced, under practical conditions, in the lowest bombs in a stack 20 ft high.

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List of Symbols

a ins.	- Radius of circular ring.
c	- A constant such that $EI_o = ct_o^3$, $EI_1 = ct_1^3$, etc.
E lb/in^2	- Young's Modulus of elasticity.
I_o $ins.^4$	- Moment of inertia of cross section of a ring of Unit width and thickness t_o.
t_1, t_2 ins.	- Thickness of bomb case or circular ring at opposite loading points.
t_3, t_4 ins.	- Thickness of bomb case or circular ring at points midway between the applied loads in the plane of loading.
t_o ins.	**- Minimum thickness of bomb case as specified on the manufacturing drawings.**
y ins.	- Observed deflection - change in diameter - of a bomb case due to equal and opposite loads W, measured along the line of action of W. Also the deflection (change in diameter) of a circular ring due to equal and opposite loads W measured along the line of action of W.
y_o ins.	- Deflection - change in diameter - of a bomb case of the specified minimum thickness due to equal and opposite loads W.
H_o lb	- Tangential thrust in the circular ring at the point A (Fig.3).
V_o lb	- Radial shear force in the circular ring at the point A (Fig.3).
M_o lb ins.	- Bending moment in the circular ring at the point A (Fig.3).
M lb ins.	- Bending moment.
θ Radians	- Angle measured around the circular ring from the origin A (Fig.3).
U lb ins.	- Strain energy stored.
W lb	- Equal and opposite loads applied to a bomb case (Fig.2) or to a circular ring (Fig.3)
α_1---α_4	- Arcs over which thicknesses t_1---t_4 respectively extend.

$$k_1 = \frac{2}{t_o^3\,(t_1^{-3} + t_2^{-3})}$$

correction factor used when the thickness of the specimen case is known only at the two loading points. Using k_1, y_o is given by $y_o = k_1 y$.

$$k_2 = \frac{4.97}{t_o^3[1.47(t_1^{-3} + t_2^{-3}) + t_3^{-3} + t_4^{-3}]}$$

correction factor used when the thickness of the specimen case is known at the two loading points and also at two points midway between them. Using k_2, $y_o = k_2 y$.

APPENDIX I

Details of Bombs Considered

Description of Bomb	External diameter at maximum section ins.	Least Thickness of Case ins.	Length of Body ins.	Construction of Body
250 lb G.P. Mk.4	10.2	0.52	27.6	Cast steel
500 lb G.P. Mk.4	12.9	0.72	36.4	Cast steel
1000 lb G.P. Mk.1) " " " Mk.2) " " " Mk.3) " " " Mk.4)	16.0 approx.	0.75	50.75	Cast steel
250 lb M.C. Mk.1) " " " Mk.2)	10.2	0.3	27.5	Cast steel
500 lb M.C. Mk.1	12.9	0.285	42.0	Fabricated steel
" " " Mk.2	"	0.285	40.9	Forged steel
" " " Mk.3	"	0.42	40.9	Cast steel
" " " Mk.4	"	0.42	36.35	" "
" " " Mk.6	"	0.285	42.0	Body similar to Mk.1
" " " Mk.7	"	0.285	41.95	" " " Mk.2
" " " Mk.8	"	0.42	40.9	Cast steel
" " " Mk.9	"	0.42	36.35	" "
" " " Mk.10	12.75	0.35	43.75	Forged steel, solid nose
" " " Mk.13	12.9	0.285	42.0	Fabricated steel
1000 lb M.C. Mk.1	17.5	0.48	50.15	Cast steel
" " " Mk.2	17.5			
" " " Mk.3	16.0	0.60	53.32	Forged steel
2000 lb A.P. Mk.2* " " " Mk.3* " " " Mk.4	13.5 13.5	1.79	76.95	Forged steel

APPENDIX II

Results of Tests applied to 500 lb M.C. Bomb Body

Table 1

Test 1 - Loads applied in the plane 9.0 ins. forwards of suspension lug

1 Load W (Fig.2)	2 Equivalent number of tiers (para.3.3) = W ÷ 261.5	3 Observed deflection, y, (change in diameter) due to the application of W. y ins.	4 Corresponding deflection, y_o, with minimum thickness of case = k_1y = 4.42y. y_o ins.
2092	8	0	0
2615	10	0	0
3138	12	0	0
3661	14	0	0
4184	16	0.01	0.0442
4707	18	0.015	0.0663
5230	20	0.02	0.0884
5753	22	0.02	0.0884
6276	24	0.0225	0.0995
6799	26	0.0225	0.0995
7322	28	0.025	0.1105
7845	30	0.03	0.1326
10,080		0.04	0.1768
11,200		0.04	0.1768
12,320		0.0425	0.1879
13,440		0.050	0.221
0		0.010*	

*Amount of permanent reduction in diameter after reducing the load W to zero.

Thicknesses of case at loading points

$$t_1 = 0.434 \text{ ins.}, \; t_2 = 0.514 \text{ ins.}$$

Specified least thickness of case = t_o = 0.285 ins.

$$\text{Correction factor (para.5.4)} = k_1 = \frac{2}{t_o^3(t_1^{-3} + t_2^{-3})} = 4.42$$

Ultimate tensile strength of material of case at loading points = 33 tons/in.^{2} and 32 tons/in.^{2}.

APPENDIX II (Contd.)

Results of Tests applied to 500 lb M.C. Bomb Body

Table 2

Test 2 - Loads applied in the plane 1.2 ins. forwards of suspension lug

1 Load W (Fig.2)	2 Equivalent number of tiers (para.3.3) = W ÷ 261.5	3 Observed deflection, y, (change in diameter) due to the application of W. y ins.	4 Corresponding deflection, y_o, with minimum thickness of case = k_2y = 2.71y. y_o ins.
2092	8	0	0
2615	10	0	0
3138	12	0.005	0.0136
3661	14	0.005	0.0136
4184	16	0.015	0.0407
4707	18	0.0175	0.0474
5230	20	0.020	0.0542
5753	22	0.0275	0.0745
6276	24	0.030	0.0813
6799	26	0.030	0.0813
7322	28	0.035	0.0949
7845	30	0.0375	0.1016
10,080		0.055	0.149
11,200		0.060	0.1626
12,320		0.070	0.1897
13,440		0.080	0.2168
0		0.01*	

*Amount of permanent reduction in diameter after reducing the load W to zero.

Thicknesses of case (Fig.1):-

t_1 = 0.328 ins., t_2 = 0.478 ins., t_3 = 0.400 ins., t_4 = 0.490 ins.

Specified least thickness of case = t_o = 0.285 ins.

Correction factor (para.5.4).

$$= k_2 = \frac{4.97}{t_o^3\left[1.47\ (t_1^{-3} + t_2^{-3}) + t_3^{-3} + t_4^{-3}\right]} = 2.71$$

Ultimate tensile strength of material of case at loading points = 32.5 tons/in.^{2} and 34 tons/in.^{2}.

APPENDIX III

Results of Tests applied to 1000 lb M.C. Bomb Body

Table 1

Test 1 - Loads applied in the plane 12.0 ins. aft of suspension lug

1 Load W (Fig. 2)	2 Equivalent number of tiers (para. 3.3) = W ÷ 612	3 Observed deflection, y, (change in diameter) due to the application of W. y ins.	4 Corresponding deflection, y_o, with minimum thickness of case = $k_1 y$ = 1.62y. y_o ins.
3672	6	0.0025	0.00405
4896	8	0.005	0.0081
6120	10	0.010	0.0162
7344	12	0.015	0.0243
8568	14	0.020	0.0324
9792	16	0.025	0.0405
11,016	18	0.030	0.0486
12,240	20	0.0325	0.0527
13,464	22	0.0375	0.0608
14,688	24	0.0425	0.0689
15,912	26	0.0425	0.0689
17,136	28	0.0475	0.0770
18,360	30	0.0525	0.0851
24,480	40	0.0725	0.1175
0	0	0.0075*	0.01215*
24,480	40	0.0725	0.1175
30,600	50	0.0975	0.1580
36,720	60	0.125	0.20250
	0	0.0275*	0.0446*

*Amount of permanent reduction in diameter after reducing the previous load W to zero.

Thicknesses of case at loading points:

$$t_1 = 0.579 \text{ ins.}, \; t_2 = 0.551 \text{ ins.}$$

Specified least thickness of case, $t_o = 0.48$ ins.

$$\text{Correction factor, (para. 5.4)} = k_1 = \frac{2}{t_o^3(t_1^{-3} + t_2^{-3})} = 1.62.$$

Ultimate tensile strength of material of case at loading points = 35.2 tons/in.^{2} and 37.5 tons/in.^{2}.

APPENDIX III (Contd.)

Results of Tests applied to 1000 lb M.C. Bomb Body

Table 2

Test 2 - Loads applied in the plane of the suspension lug

1 Load W (Fig. 2)	2 Equivalent number of tiers (para. 3.3) $= W \div 612$	3 Observed deflection, y, (change in diameter) due to the application of W. y ins.	4 Corresponding deflection, y_o, with minimum thickness of case $= k_2y = 1.72y$. y_o ins.
3672	6	0	0
4896	8	0.005	0.0086
6120	10	0.010	0.0172
7344	12	0.015	0.0258
8568	14	0.025	0.0430
9792	16	0.030	0.0516
11,016	18	0.035	0.0602
12,240	20	0.040	0.0688
13,464	22	0.0475	0.0817
14,688	24	0.050	0.0860
15,912	26	0.0575	0.0989
17,136	28	0.0625	0.1075
18,360	30	0.0675	0.1161
24,480	40	0.100	0.1720
0	0	0.005*	0.0086*
24,480	40	0.100	0.1720
30,600	50	0.1275	0.2193
36,720	60	0.165	0.2838
0	0	0.030*	0.0516*

*Amount of permanent reduction in diameter after reducing the previous load W to zero.

Thicknesses of case (Fig. 1):-

$t_1 = 0.567$ ins., $t_2 = 0.555$ ins., $t_3 = 0.600$ ins., $t_4 = 0.590$ ins.

Specified least thickness of case = 0.48 ins.

Correction factor (para. 5.4)

$$= k_2 = \frac{4.97}{t_o^3\left[1.47\left(t_1^{-3} + t_2^{-3}\right) + t_3^{-3} + t_4^{-3}\right]} = 1.72.$$

Ultimate tensile strength of material of case at loading points $= 38.5$ tons/in.^{2}.

APPENDIX IV

Derivation of the Correction Factors k_1 and k_2 (para.5.4)

Consider a ring of uniform width and mean radius a to which equal and opposite loads W are applied at A and B as shown in Fig.3(a). On the section just to the right of the point A there will, in general, be a moment M_o, a shear force V_o, and a direct force H_o (Fig.3(b)). If the ring is of uniform radial thickness, $V_o = \frac{1}{2}W$, $H_o = 0$ and $M_o = \frac{Wa}{\pi}$. If the ring is not uniform in thickness, V_o, H_o, and M_o differ slightly from these values, but for the present purpose, and for the variations which have to be considered here, such differences are considered small enough to be neglected.

With the usual notation and the usual assumption that only the strain energy in bending need be considered, the deflection of A relative to B (Fig.3(a)) is

$$y = \frac{\partial U}{\partial W} = \frac{\partial U}{\partial M} \cdot \frac{\partial M}{\partial W} = \frac{1}{E}\int_{\theta=0}^{\theta=2\pi} \frac{M}{I} \cdot \frac{\partial M}{\partial W} \cdot a\,d\theta \qquad (1)$$

For a ring of uniform width and uniform radial thickness t_o we may write $EI = ct_o^3$ where c is a constant, so that

$$y = y_o\text{, say, } = \frac{a}{c}\int_{\theta=0}^{\theta=2\pi} \frac{M}{t_o^3} \cdot \frac{\partial M}{\partial W}\,d\theta = \frac{4a}{ct_o^3}\int_{\theta=0}^{\theta=\pi/2} M \cdot \frac{\partial M}{\partial W}\,d\theta \qquad (2)$$

Taking the values of V_o, H_o and M_o given above we have, at any point "X" defined by θ (Fig.3(B)),

$$M = M_o - V_o a \sin\theta = Wa\left(\frac{1}{\pi} - \frac{1}{2}\sin\theta\right) \text{ so that } M\frac{\partial M}{\partial W} = Wa^2\left(\frac{1}{\pi} - \frac{1}{2}\sin\theta\right)^2$$

and substituting this in (2),

$$\text{for the uniform ring, } y_o = \frac{4Wa^3}{ct_o^3}\int_{\theta=0}^{\theta=\pi/2} \left(\frac{1}{\pi} - \frac{1}{2}\sin\theta\right)^2 d\theta = \frac{0.149Wa^3}{ct_o^3} \qquad (3)$$

If, instead of being uniform, the ring is of two thicknesses t_1 and t_2 each of which extend over half the circumference between points, on the same horizontal diameter, equidistant from A and B (Fig.3(a)) then the deflection, y, of A relative to B would be given (from equation (3)) by

$$y = \left(\frac{0.149}{2}\right)\frac{Wa^3}{c}\left[\frac{1}{t_1^3} + \frac{1}{t_2^3}\right] = \frac{0.0745Wa^3}{c} \cdot (t_1^{-3} + t_2^{-3}) \qquad (4)$$

APPENDIX IV (Contd.)

Comparing (3) and (4) it is seen that the value of the correction factor (para. 5.1), $y_o/y = k_1$, for use in the formula $y_o = k_1 y$ is

$$k_1 = \frac{0.149}{t_o^3} + 0.0745\left(t_1^{-3} + t_2^{-3}\right) = \frac{2}{t_o^3\left(t_1^{-3} + t_2^{-3}\right)} \qquad (5)$$

If the ring is of four different thicknesses t_1, t_2, t_3 and t_4 (Fig. 1 Appendix II and Fig. 1 Appendix III), each extending over a quarter of the circumference with t_1 and t_2 extending an equal distance, circumferentially, each side of A and B respectively then the deflection of A relative to B is

$$y = \frac{a}{ct_1^3}\int_{\theta=-\pi/4}^{\theta=\pi/4} M\frac{\partial M}{\partial W}\,d\theta + \frac{a}{ct_4^3}\int_{\theta=\pi/4}^{\theta=3\pi/4} M\frac{\partial M}{\partial W}\,d\theta$$

$$+ \frac{a}{ct_2^3}\int_{\theta=3\pi/4}^{\theta=5\pi/4} M\frac{\partial M}{\partial W}\,d\theta + \frac{a}{ct_3^3}\int_{\theta=5\pi/4}^{\theta=7\pi/4} M\frac{\partial M}{\partial W}\,d\theta \qquad (6)$$

By symmetry, and by analogy with (3)

$$a\int_{\theta=-\pi/4}^{\theta=\pi/4} M\frac{\partial M}{\partial W}\,d\theta = a\int_{\theta=3\pi/4}^{\theta=5\pi/4} M\frac{\partial M}{\partial W}\,d\theta = 2a\int_{\theta=0}^{\theta=\pi/4} M\frac{\partial M}{\partial W}\,d\theta$$

$$= 2Wa^3\int_{\theta=0}^{\theta=\pi/4}\left(\frac{1}{\pi} - \frac{1}{2}\sin\theta\right)^2 d\theta = \underline{0.044Wa^3} \qquad (7)$$

similarly, $$a\int_{\theta=5\pi/4}^{\theta=7\pi/4} M\frac{\partial M}{\partial W}\,d\theta = a\int_{\theta=\pi/4}^{\theta=3\pi/4} M\frac{\partial M}{\partial W}\,d\theta$$

$$= Wa^3\int_{\theta=\pi/4}^{\theta=3\pi/4}\left(\frac{1}{\pi} - \frac{1}{2}\sin\theta\right)^2 d\theta = \underline{0.03Wa^3} \qquad (8)$$

APPENDIX IV (Contd.)

Substituting from (7) and (8) in (6) we have

$$y = \frac{Wa^3}{c}\left[0.044\left(t_1^{-3} + t_2^{-3}\right) + 0.03\left(t_3^{-3} + t_4^{-3}\right)\right] \qquad (9)$$

so that the value of the correction factor (para. 5.1), $y_o/y = k_2$ say, for use in the formula $y_o = k_2 y$ is, from (3) and (9),

$$k_2 = \frac{0.149}{t_o^3} \div \left[0.044\left(t_1^{-3} + t_2^{-3}\right) + 0.03\left(t_3^{-3} + t_4^{-3}\right)\right],\ \text{that is}$$

$$k_2 = \frac{4.97}{t_o^3\left[1.47\left(t_1^{-3} + t_2^{-3}\right) + t_3^{-3} + t_4^{-3}\right]} \qquad (10)$$

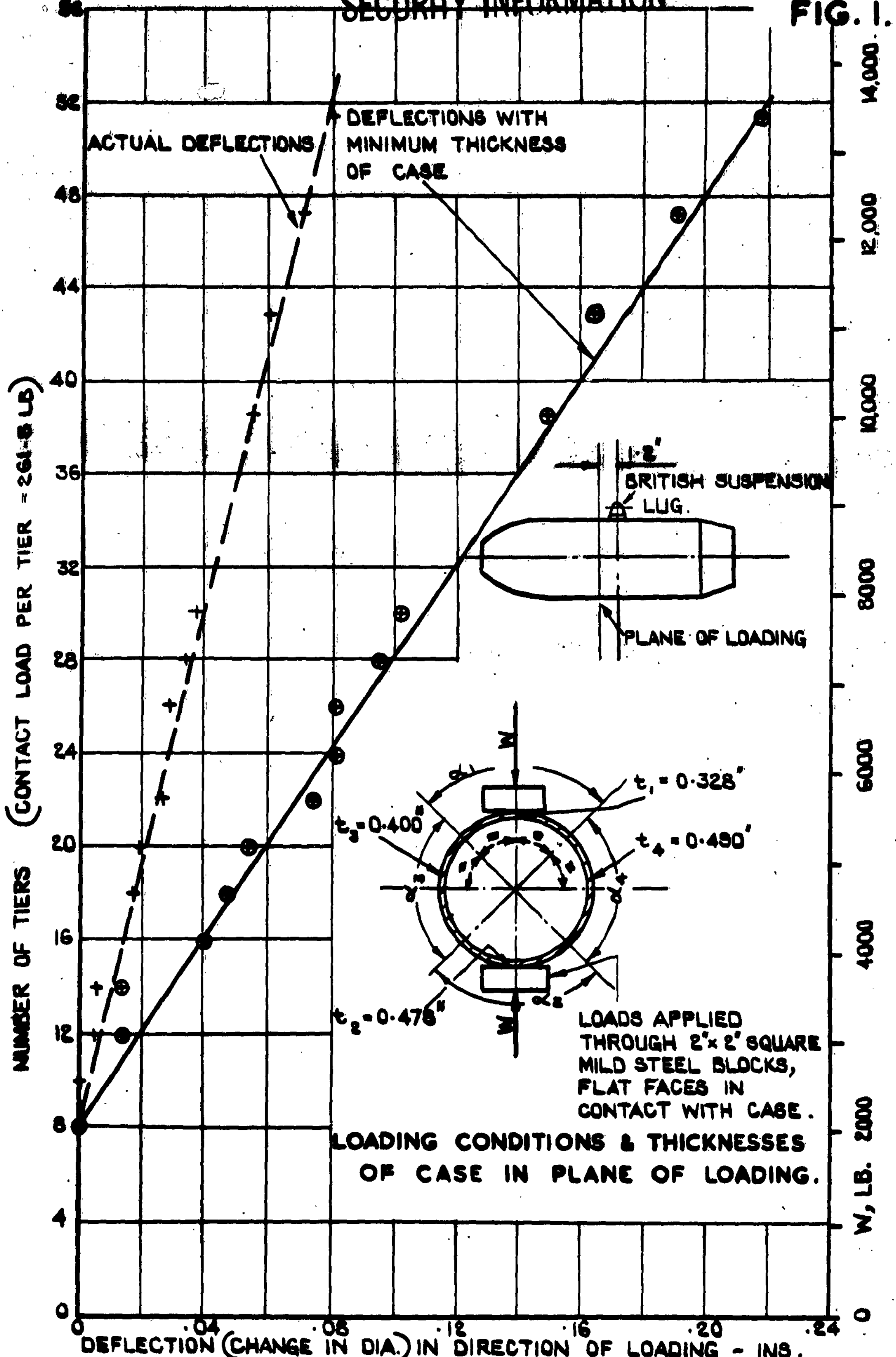

FIG. 1. APPENDIX II. TEST ON 500 LB. M.C. BOMB CASE (TEST 2 OF APPENDIX II).

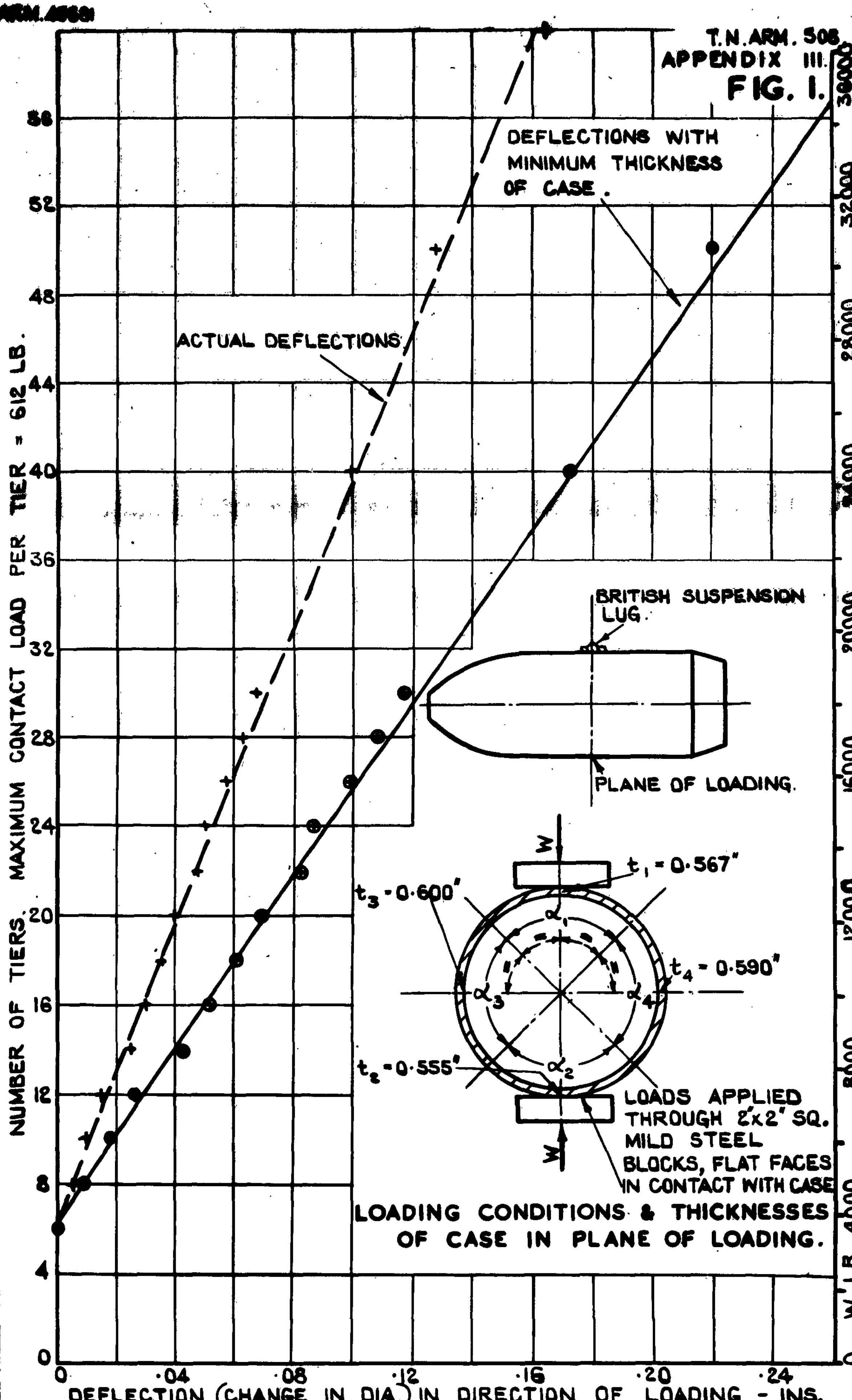

FIG. I. APPENDIX III. TEST ON 1000LB. M.C. BOMB CASE (TEST 2 OF APPENDIX III)

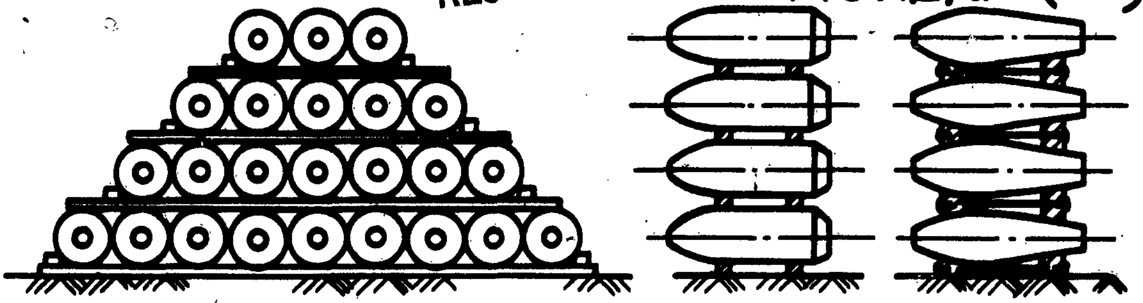

FIG. 1. BOMBS STACKED IN LAYERS WITH INTERVENING BATTENS.

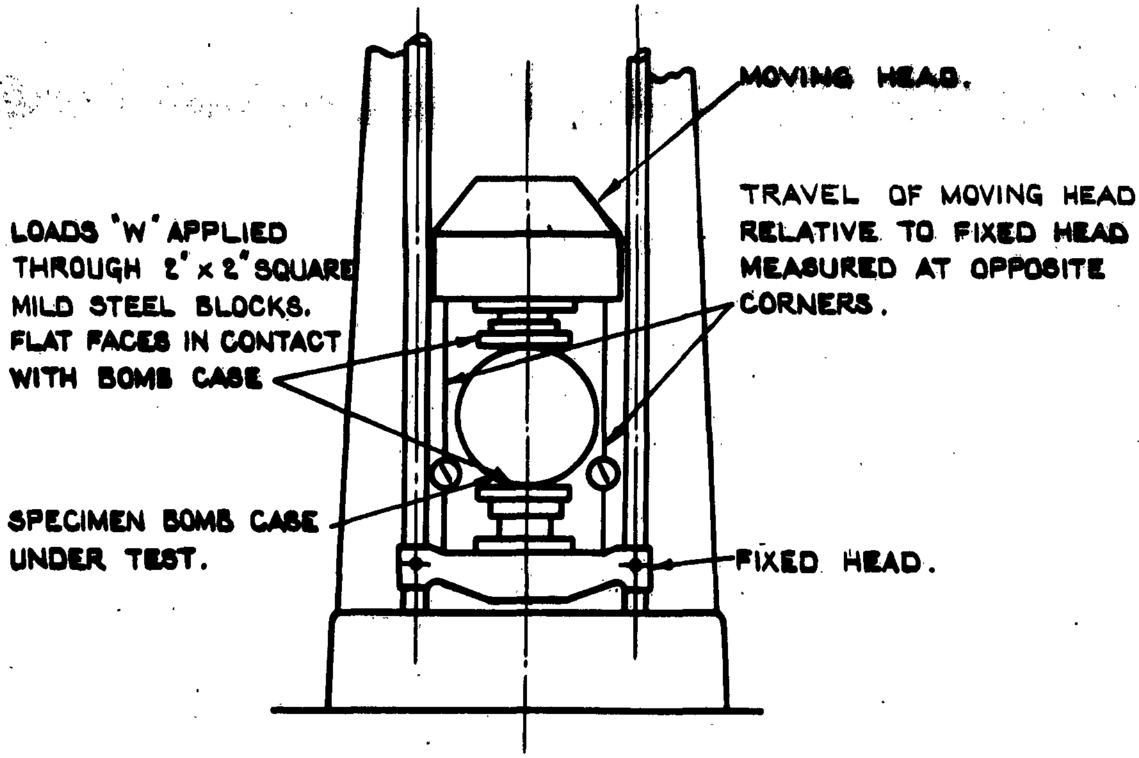

FIG. 2. METHOD OF APPLYING TEST LOADS.

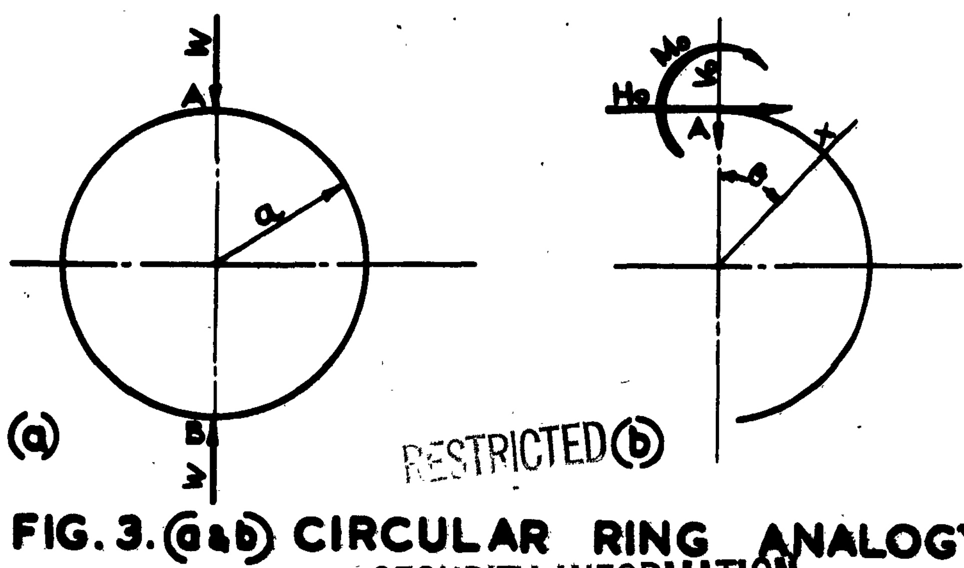

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FIG. 3. (a & b) CIRCULAR RING ANALOGY.

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Bombs H.E., A/C, M.C., 250 lb, 500 lb and 1000 lb.

Bombs H.E., A/C, A.P., 2000 lb.

The maximum deflections given enable a safe stacking height to be deduced for each store from a knowledge of the maximum allowable disturbance of filling.

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Date of Search: 13 February 2009

Record Summary: AVIA 6/19450
Bomb case deflections under stacking loads
Former reference (Department): TECH NOTE ARM 508
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